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APPLICATION OF RECENT HYPOTHESES TO CHANGES OF SEALEVEL IN BASS STRAIT, AUSTRALIA

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ABSTRACT: The shores of Bass Strait are (1) stormy, (2) microtidal, and (3) of Mediterranean climate. Hypotheses related respectively to each of these fundamental factors are examined.

1. *Storminess.* Emerged high energy deposits such as boulder beds have been explained by a period of greater storminess with the sea at its present level. Wilson and Hendy (1972) show that great storminess is associated with lower sealevels when the thermal gradient between poles and equator was greater. A higher sealevel is therefore a more acceptable interpretation for the emerged boulder beds of Bass Strait, especially when they overlie an ancient platform too high to be cut by present sealevel and covered by weathered colluvium.
2. *Small Tidal Range.* West Bass Strait has a tidal range ~ 1 m, which increases to the east. Davies (1964) has shown the significance on a world scale of tidal range. In west Bass Strait the small tidal range concentrates marine attack, strongly eroding any soft bed within its limits. High tides from meteorologic effects may reach x 2·6 normal range, thus developing the supratidal zone. Biologic and physical zones are compressed, while tidal currents are negligible, and salt marsh development depressed.
3. *Climate.* Authors have placed the power of the sea (physical) and water layer weathering (chemical) in apposition, regarding the latter as universally operative as the former. Gill (1972) considers the latter to be a function of the tropics, and the pools on platforms in Bass Strait to be of quite a different character.

INTRODUCTION

Bass Strait is stormy, microtidal, and Mediterranean in climate. These three fundamental characteristics strongly influence the nature of the shores, and so the record of the changes of sealevel. To understand present processes is to improve ability to read the evidence of past sealevels. Recently, new hypotheses have been advanced relevant to each of the above three characteristics of Bass Strait. It is of value to examine how these hypotheses affect the interpretation of its coasts. Moreover, this procedure produces new programmes for the study of sealevel shifts.

STORMINESS IN BASS STRAIT

Bass Strait is the waterway between Victoria and Tasmania. Both these States have lakes near enough to the sea to suffer comparable subaerial weathering, yet the marine shores and the lake shores possess quite different morphologies. The chief reason is the different energy status, the former being high and the latter low. The shores of Bass Strait are highly energetic; they yield (for example) supratidal platforms and boulder beds not seen on lake shores. On the sea coast, the change in morphology from exposed headland to quiet inlet is largely a function of decreasing dynamics.

Boulder beds now above the reach of the stormiest seas are found on the north coast of Tasmania (Chick 1970, Davies 1961, 1965, Jones 1965), King Island (Jennings 1959), and the south coast of Victoria (Gill 1972a,b). Boulder beds exist above the reach of the stormiest seas, i.e. the most energetic waves no longer hit these boulders, much less move them. Indeed, they are often covered with colluvium and/or soil plus vegetation, and the higher ones overlie weathered platforms. Occasional big storms may throw up boulders, but they cannot cut a platform. Boulder beds in three situations have been noted on the Otway coast of Victoria:

1. *Arkose boulders with shells* on an extension of the present siltstone and arkose intertidal

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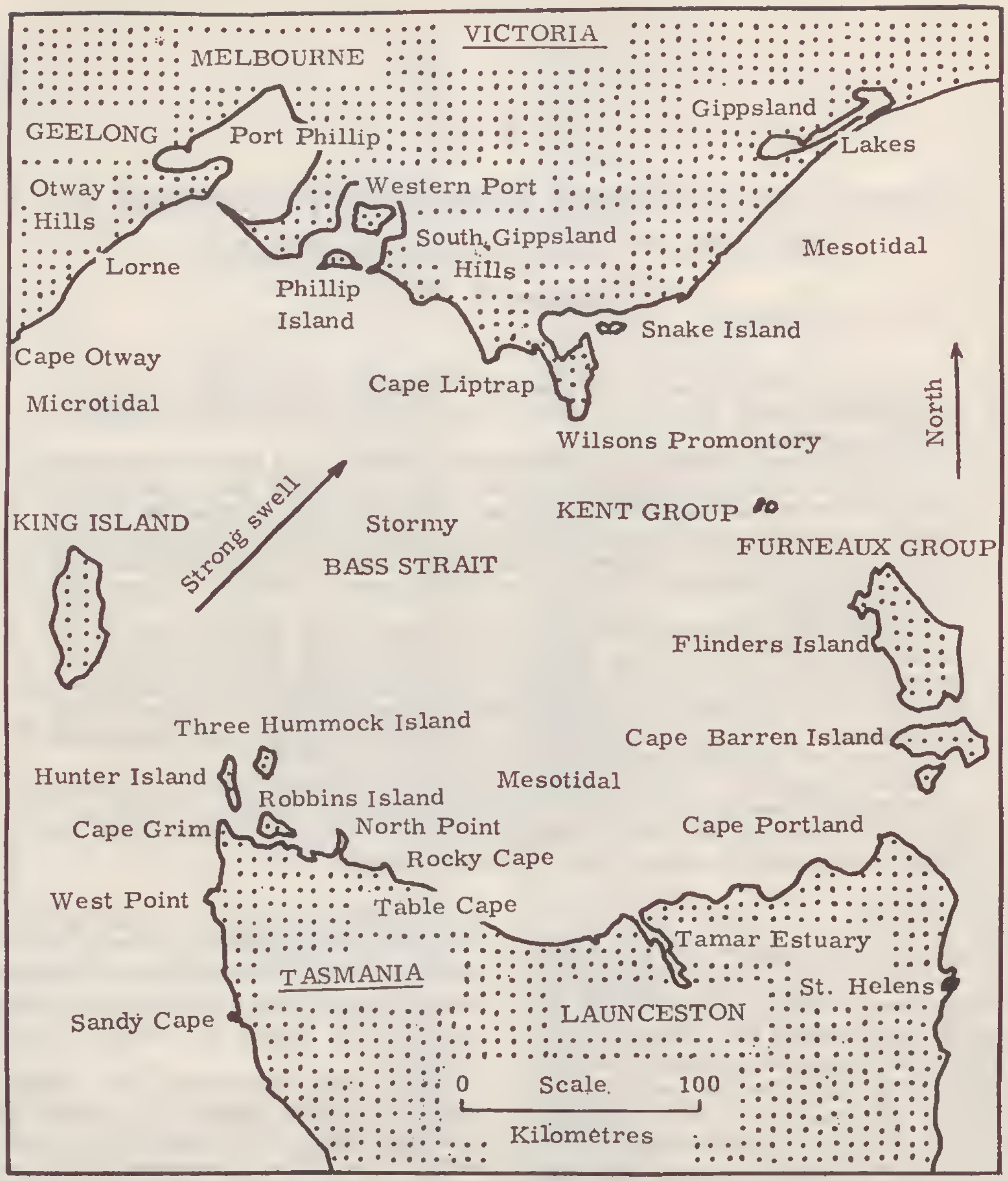

Fig. 1—Map of Bass Strait with indications of microtidal and mesotidal areas, plus direction of swell.

platforms, covered with sand plus vegetation. Considerable energy would be necessary at the site to emplace these boulders, but the present sea does not even wash away the sand and soil. This has been the condition for a long while, because a soil has formed on the sand. For surveyed sections see Gill 1972, Figs. 2-3. At Browns Creek, marine shells occur among the boulders of such a bed, while SW. of Boggaley Creek, beach rock formed by groundwater was found over and among such boulders. Radiocarbon assays are being made of the organic materials.

2. *Boulders with shells* forming a ramp behind a supratidal platform, commonly as the continuation of a channel or such structure (Gill 1972 b, Figs. 10-11). The boulders now have soil between them and often over them plus vegetation (sometimes trees). These deposits could be the supratidal environment equivalent of (1) above.

3. *Boulders without shells* on an emerged plat-

form, both weathered, standing ~ 7·5 m (surveyed at Cumberland River) above present low sealevel (tidal range ~ 1 m) and commonly covered by a thick colluvium (up to 20 m) of red soil and unsorted angular rocks capped by a gray soil. In north Tasmania, boulder beds occur covered by forest.

The interpretation of boulder beds has always been a matter of considerable uncertainty, the chief misgiving being that such may be the record of a more stormy period with sealevel as at present, and not evidence of a sealevel change. Thus usually the very high boulder beds have been accepted as evidence of shift of sealevel, but not the lower ones. For example, Jones (1965) described a seaward-facing cave near Wynyard in which a cemented water-rolled conglomerate adheres to parts of the ceiling. From this he deduced a former sealevel of the order of 30 m above the present. On the other hand, the boulder beds I list above have been explained as a function of storms.

On this question, the hypothesis of Wilson and Hendy (1972) has a direct bearing. Storminess is described as a function of the difference in mean temperature between the equator and the poles. This difference can be traced in the past by oxygen isotope analyses. The assay of deep polar cores provides the information previously missing to check such an idea. On this hypothesis, the periods of great storminess existed when the poles were coldest and sealevels lowest; the periods of least storminess existed when the poles were warmer than now and sealevels higher. It is therefore unlikely that the emerged boulder beds are due to a period of great storminess with the sea at its present level. Conversely, it *is* likely that they were due to a higher sealevel bringing the dynamics of the waves into play higher on the coastline. These considerations apply also to other high energy emerged coastal deposits such as storm beaches, terraces of coarse shell grit, and platforms in exposed positions now covered with soil plus vegetation.

Beneath the sea on the continental shelf many deposits of course sediments that apparently belong to former lower shorelines have been found. When these have been studied further, they should throw light on the question of to what extent higher dynamics are associated with the lower sealevels. In Australia during the Last Glacial, there were more widely spread active dune systems than at present.

Approaching the subject of the Bass Strait boulder beds from another angle, it may be anticipated that, if they are a record of higher sealevels, correlative stillwater marine facies at this level should be present, when due allowance has been made for the fact that they erode more easily than boulder beds. By reason of the rapid rate of retrogradation on aeolianite coasts, for example (~ 4 cm/yr in west Victoria), it is unlikely that the open ocean facies of previous higher sealevels will remain. However, on coasts of resistant rocks, such as fresh basalt, it should be possible to locate both the open ocean and the stillwater facies because of the slow rate of wear. Indeed this has been done on the Woodbine Basalt (Gill 1973) between Port Fairy and Cape Reamur, west Victoria. On the open coast emerged channels, emerged potholes, shell grit terraces out of reach of the sea, and such have been found. Postglacial dates of various ages have been obtained. *Katelysia* shells from a stillwater facies behind a basalt barrier, at the South Beach caravan park, Port Fairy, were dated 3880 ± 90 y BP (GaK-3918). On the open ocean coast, an emerged channel with well-rounded boulders (up to 1 m diameter but usually less) and shell grit was dated 2840 ± 80 y BP (GaK-3917) on whole to partly broken shells. These dates correlate with some obtained elsewhere, but more work needs to be done to match contemporaneous high and low energy facies of various ages at a number of points along the coast. The main difficulty is that this requires resources for numerous excavations and numerous radiocarbon assays.

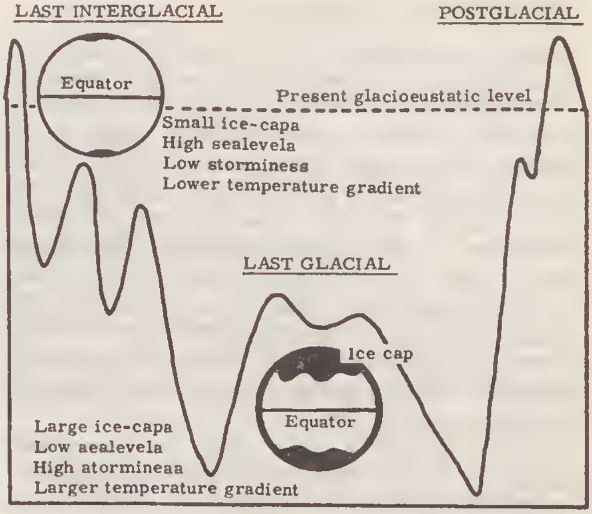

FIG. 2—Generalized graph (after Emiliani) of temperature changes, and therefore also of glacioeustatic sealevel changes, since the Last Interglacial. Gross changes in polar-equatorial temperature gradients with time, and their results, are indicated.

MICROTIDAL SHORES

With the emergence of the science of ecology, some attention has been given to this aspect of coastal studies. Davies (1964) provided a fresh approach by pointing out the relevance to the coasts of the world of tidal range and swell régime. Bass Strait is microtidal in the west half, and grades into mesotidal in the east. Because the Southern Hemisphere is the ocean hemisphere, the storm belt is very much better defined than in the Northern Hemisphere. One result is a strong swell régime. Southwest swell dominates the seas of the south side of Australia, and it has been 'invoked to explain beach alignment in southern Australia generally' (Davies 1960).

Taking up Davies' point about the importance of tidal range, the writer has noted the following distinctive features of the microtidal rocky coasts of Bass Strait:

1. *Concentration of Marine Attack.* The surf zone is one of Nature's power tools. In that zone the main erosive work of the shoreline is done. On a macrotidal coast of say 10 m, the surf zone passes across the (usually) wide rock platform as the tide comes in. However, on a microtidal coast of say 1 m, there is less transgression, and so the amount of erosion at a given site is much greater. Expressed another way, it can be said that, at a given site on a macrotidal coast of 10 m tidal range, the number of broken wave and swash strikes will be x, while on a microtidal coast of 1 m tidal range it will be 10 x. Thus a concentration of sea energy occurs on the microtidal coast, which results in a more rapid landward move of the shoreline profile. The average number of times that a heavy boulder in a pothole or channel is agitated by high energy waters per tidal change is much greater on a microtidal than on a macrotidal coast. Therefore, the amount of corrasion is much greater. The average number of high energy water impacts on a joint block on a microtidal coast is far greater than on a macrotidal coast, and so the amount of quarrying (Gill 1972) and plucking (Gill 1971) is much greater per unit area.

Similarly, the number of times armed surf (i.e. laden with rocks, sand and shells) sweeps over a given square metre of shore rock is much higher on a microtidal than on a macrotidal coast. Therefore, the amount of abrasion is much greater thereon. In the extreme case where the tidal range is of the order of only (say) 30 cm, the marine attack is virtually on the same level at the time and so very concentrated. Retrogradation is then faster. As Davies (1964, p. 137) says, 'The importance of variation in water level is obvious enough, for this determines the degree to which wave attack is concentrated on a particular plane.'

2. *Area for platform species is less.* The number of square metres available for the accommodation of intertidal organisms is much less on a microtidal coast than a macrotidal one (other things being equal), but as far as I have been able to observe the distribution per unit area is not significantly different, so the effects of biologic activity are much the same per unit area on the two types of coast. Thus there is a much smaller biomass of intertidal life on a microtidal coast than on a macrotidal one. Because there is so much more life in the intertidal zone of a macrotidal coast, industries such as the collection of seaweed are to be found on such coasts, e.g. Brittany.

3. *Erosion of Soft Strata Dependent on Critical Placement.* Because the zone of surf attack on a microtidal coast is so narrow, the level at which a layer of soft (and so readily erodable) rock occurs is very critical, as also is its disposition (dip and strike). For instance, a horizontal palaeosol in aeolianite within or near a 1 m tidal range (which we have taken as an example of a microtidal situation) will be rapidly eroded and cause massive cliff falls. Conversely, if it lies in the upper supratidal zone, it is likely to be lithified by the accumulation of secondary carbonate.

Or again, a soft siltstone 0·3 m thick in much harder arkose strata, as on the Otway coast of Victoria, can cause rapid demolition if it occurs within the 1 m tidal range. Opposite Little Stony Creek at Lorne, Victoria, a soft siltstone occurs in the horizontal arkose strata within the narrow tidal range, and is being tunneled by marine erosion, resulting in collapse of the overlying rocks. Pebbles washed round in these tunnels rapidly abrade the walls and widen the channels, admitting more sea and pebbles.

At Boggaley Creek, further SW. on the same coast (NE. of Wye River) the strata strike oblique to the shore and dip at 30°. A siltstone band, brought into the tidal range by the dip of the strata, is being rapidly eroded by the sea, causing collapse of the overlying arkose, which breaks up according to its joint pattern. One result is an exceptionally large number of boulders on the shore platform (SW. side of creek). These are moved by the sea and so increase erosion. Thus the position of a soft stratum is critical on a microtidal coast because the erosion zone is so narrow, and the marine attack so concentrated.

4. *Meteorologic Variation of Tidal Range is Significant.* On a macrotidal coast, the degree to which tides are lower or higher because of weather

conditions is not usually a large percentage of the tidal range. Lower tides are caused by strong offshore winds, for example, and higher tides by onshore ones. On a microtidal coast, however, such differences may be a significant percentage of the tidal range or even exceed it. At Hobsons Bay, Melbourne, normal tidal range is 0·76 m, but abnormally high tides due to meteorologic conditions have been recorded up to 1·96 m, which is 2·6 times the norm (Bradley 1949, 1955, 1957).

5. *Dominating Supratidal Zone.* Where a coast is stormy and microtidal, the supratidal zone ranges through a greater elevation than the intertidal zone. On the Otway coast of Victoria, where the hills commonly come down steeply to the sea, the spindrift from storms rises to the order of 100 m as the leaves killed by salt testify. This would be an extreme definition of a supratidal zone. Some would define this zone by the height of splash, but this varies greatly according to the exposure of the site, the morphology of the rocks against which the waves break, and the depth of water offshore. Probably the best definition is the biologic one. Nerite molluscs are characteristic of this zone and they can be used to define it. Because on a stormy microtidal coast the tidal range is narrow and the storm waves rise high, there is a great deal of activity above high water level. Because the plane of marine attack does not alter much, there is a concentration of energy in the supratidal zone during storms, with the result that abrasion occurs that would not take place on a macrotidal coast. Therefore *supratidal shore platforms are more readily developed in such an environment than elsewhere.* More erosion of the cliffs takes place, and more rock falls occur. Thus, while rocks are absent or rare on some platforms, they are common on the platforms of stormy microtidal coasts. These boulders provide the tools for further erosion.

6.*Tidal Currents Negligible.* On macrotidal coasts the large tidal range results in powerful tidal currents which deeply scour the subtidal zone. On a microtidal coast the movements of water are comparatively small and smooth, so that tidal currents are negligible, and this is not one of the significant erosive energies of that environment.

7. *Biologic Zonation Compressed.* Because of the narrow tidal range on a microtidal coast, the biologic zones of the intertidal belt are compressed, so that they also are very narrow. To illustrate again from western Victoria, five biologic zones can be distinguished in the small tidal range of 1 m.

8. *Physical Zonation Compressed.* On the exposed microtidal basalt coasts between Port Fairy and Cape Reamur in west Victoria, one can distinguish a series of erosional zones along the shoreline. There are pavements where the main force of the ocean's energy is effective to quarry blocks of basalt along joint planes and throw them further back on the shore profile. There is a zone where the boulders are not swept away, but the energy is high enough to agitate them to excavate pools and potholes. Then there is the zone of general boulder accumulation. Above that is a zone characterised by subaerial weathering. As the plane of marine attack is much narrower on a microtidal coast, these physical zones are naturally much more compressed than on a macrotidal coast.

9. *Salt Marsh Development.* Broad salt marsh development characterises the macrotidal coast, but is very depressed on a microtidal coast because of the small tidal range. On the latter, salt marsh development is minor. Salt marshes on a small scale are found beside tidal creeks, and in such sites.

The features of a microtidal coast listed above are sufficient to prove that the narrow tidal range has many implications, resulting in a characteristic type of shoreline organization. Narrow tidal range places its own impress on a coast. In coastal descriptions, therefore, it is important that the tidal range be given, and any special characteristics that accompany it. In west Bass Strait the coast is microtidal, and on many days only one high and one low tide occur, instead of the usual two highs and two lows. This is the tidal type C of King (1959). This characteristic even further reduces the limited tidal energy of the coast and so the tidal currents can be neglected as a source of erosive energy. On the other hand, there is a fetch all the way from Australia to Antarctica, and

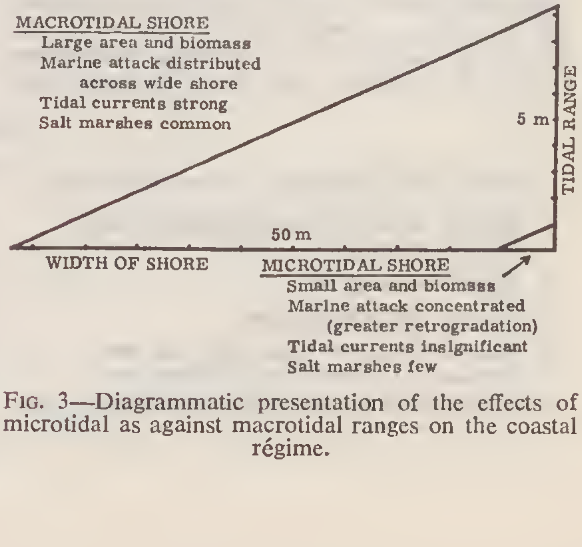

FIG. 3—Diagrammatic presentation of the effects of microtidal as against macrotidal ranges on the coastal régime.

the coast is characterised by powerful winter storms. Even in fine weather there may be a heavy swell from the southwest. This study emphasises the need to further apply the concepts of ecology to the study of shorelines.

ECOLOGIC CONTROL OF WATER-LAYER WEATHERING

Modern shoreline studies began on the stormy macrotidal coasts of Great Britain. The power of the sea was obvious. It was considered the chief agent in coastal erosion. Later, Wentworth (1938) studied shore platforms in the lower energy tropical Hawaiian islands, and drew attention to the strong chemical weathering of the rocks by water pools (water layer weathering). Many subsequent workers have:

1. Placed these two processes in apposition. Their argument is that the chief agent of coastal reduction is not the physical power of the sea, but the chemical effectiveness of water layer weathering. The role of the sea has been played down, some regarding it merely as the transporting agent that carries away the products of weathering.

2. Regarded effective water layer weathering as a universal phenomenon, that applies as much to the temperate and frigid zones as to the tropical one where it was first described. Authors have used this process to account for shoreline phenomena in Bass Strait.

The writer (Gill 1972a) has hypothecated that *water layer weathering as originally described is a function of the chemically aggressive tropical climate, and is not significant in the temperate and frigid zones;* it is a process under ecologic control.

The writer's view is that:

1. *Marine erosion and water layer weathering should not be put in apposition*. The power of the sea is obvious in quarried blocks, boulder formation high above HWL, cliff retreat, cave formation and demolition, destruction of sea walls, and wrecks. Moreover, it is a universal phenomenon varying in intensity with local climate. Thus, water layer weathering and storm effects occur together in Hawaii. MacDonald and Abbott (1970, p. 196) record: 'Blocks of lava rock up to 12 ft long and weighing as much as 15 tons, have been thrown by waves onto the shore platform, in some places 30 ft above sealevel, along the Puna coast of the island of Hawaii.' Johnson (1919) reported water pressures measured by dynanometer along the Scottish coast of over 6000 pounds per square foot. Sparks (1960) says 'Large masses of spray have been recorded moving upwards at 70 mph, while small jets have been observed with the astonishing speed of over 170 mph.' Sussmilch (1912) gave an example of powerful wave action on the coast at Bondi in N.S.W., where a block of sandstone ~ 235 tons was 'elevated through a vertical distance of at least 10 feet, and then carried along a horizontal distance of about 160 feet', being turned over in the process. Bass Strait is stormy, and the cliffs, shore platforms, boulder beds, and such along its coasts bear witness to the power of sea.

2. *By contrast with marine erosion, water layer weathering is not universal but restricted to the tropics.* It yields a characteristic morphology of pools with vertical or undercut walls that often stand above the level of the water. Such have been described also by Kaye (1959) in Puerto Rico (wet tropics), and Guilcher (1958, Plate 1c) in Morocco. No such structures have been described from the shores of Bass Strait. The pools that do occur are no different from those beside a lake, on a road, or on the general terrain—simply depressions filled with water. Bartrum (1938) correctly commented that if the platforms he had described were a function of water layer weathering, 'then one would expect to see similar benches on the sheltered sides of outlying exposed stacks and islets; yet this is not the case on the Auckland coast.'

The only raised edges noted on Bass Strait shores are due to mineralized joints—iron oxides, pyrite and carbonates. The iron oxide ones are the commonest and on the Otway coast result from

TABLE 1

Water layer weathering in tropical climates	*Pools on Bass Strait shore platforms*
1. Stepped series of pools simulating sinter terraces in form.	Shallow localized pools.
2. Flat bottomed pools.	Pools with concave floors.
3. Vertical or undercut sides.	No distinctive edges.
4. Rims stand above water level and are commonly covered with *Lithothamnion*	No rims and no bordering biota.
5. Rapid chemical weathering in persistent pools.	No readily recognizable chemical weathering in ephemeral pools.

oxidation of the pyrite. These ridges have nothing to do with water layer weathering as they are a function of differential erosion. Soluble rocks such as aeolianite have pools, but again they have no raised edges. The process of solution is not nearly as well developed as in tropical areas (Wentworth 1939).

On present understanding, the differences may be summarized as shown in Table 1 on previous page.

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DESCRIPTION OF PLATES

Plate 5

Aerial oblique photograph by Keith Cecil of shore platforms at Lorne, Otway coast, Victoria, at low tide. The view is approximately NE. Note beach sand at landward edge of platform, and the subtidal extension of the platform.

Plate 6

Boulder bed on the present shore *c.* 0·5 km SW. of St. George River, Otway coast, Victoria. General view (upper photo) and detail of boulders (lower photo).

Plate 7

Small bay SW. of Boggaley Creek, Otway coast, Victoria, showing present active boulder bed, behind which is beach, and beyond which is a Holocene boulder bed with shell; it is partly covered with flotsam but extends behind that, where it is covered with sand and vegetation, ending at a fossil cliff (upper photo).

Pleistocene boulder bed without shell in roadcut on Ocean Road *c.* 0·5 km SW. of St. George River, Otway coast, Victoria. It is covered by a thick bed of red colluvium (including angular rocks) which is capped by a dark gray soil (lower photo).